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CUMULATIVE CREEP FATIGUE DAMAGE IN 316 STAINLESS STEEL

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The cumulative creep-fatigue damage behavior of 316 stainless steel at 1500 °F has been experimentally established for the two-level loading cases of fatigue followed by fatigue, creep fatigue followed by fatigue, and fatigue followed by creep fatigue. The two-level loadings were conducted such that the lower life (high strain) cycling was applied first for a controlled number of cycles and the higher life (low strain) cycling was conducted as the second level, to failure. The target life levels in this study were 100 cycles to failure for both the fatigue and creep-fatigue low life loading, 5000 cycles to failure for the higher life fatigue loading and 10 000 cycles to failure for the higher life creep-fatigue loading. Results of the fatigue followed by fatigue loading experiments follow the behavior predicted by the double linear damage rule and damage curve approach of Manson and Halford (ref. 1), while the remainder of the two-level experiments produced results that were inadequately predicted by this approach. These experiments all involved creep-fatigue loading and likely introduced a different damage mechanism from a cumulative damage standpoint. The failed specimens are being examined both fractographically and metallographically to ascertain the nature of the damaging mechanisms that produced failure. Models of creep-fatigue damage accumulation are being evaluated and knowledge of the various damaging mechanisms is necessary to ensure that predictive capability is instilled in the final failure model.

EXPERIMENTAL RESULTS AND DISCUSSION

A strainrange partitioning (SRP) characterization of this material was performed for the PP and CP damage modes at 1500 °F. While a complete SRP characterization for this material at this temperature has been established by Kalluri (ref. 2), the emphasis in that work was on the effect of exposure time on the low-cycle fatigue life; the life data so developed are over a range that was considered too narrow for the purposes of the present cumulative creep-fatigue damage study. Since, in fatigue, the nonlinear cumulative effects depend strongly on the relative life levels involved in the loading, the present study is focused on obtaining failure data at two widely separated life levels, both under pure fatigue and creep-fatigue loading. To this end, baseline SRP experiments were performed to establish the inelastic strain range levels for 100 and 5000 cycles to failure in PP and 100 and 10000 cycles to failure in CP. Results of these baseline characterization experiments are shown in figure 1. The resulting life relationships expressed in terms of inelastic strain range versus cyclic life are substantially different in the lower life regime and appear to approach each other in the longer life regime.

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These life relationships were used to determine the life levels corresponding to the loading levels applied in the two-level loading experiments.

The results of the two-level loading experiments involving PP followed by PP loadings are shown in figure 2. Substantial cyclic hardening was observed at the low life level, which served to influence the cyclic behavior observed at the (subsequent) high life level. The material response at the second loading level was different from that observed for experiments involving that loading level alone, in the respect that it exhibited much higher stresses for the applied strains. As the second level cycling progressed, the material cyclically softened and tended to approach the stabilized cyclic response observed in the baseline fatigue characterization experiments. The failure data in figure 2 are well represented by the damage curve approach of Manson and Halford (ref. 1), and are unconservatively represented by the linear damage rule of Miner (ref. 3).

The results of the two-level loading experiments involving PP followed by CP loadings are shown in figure 3. In this case as well, the influence of the substantial amount hardening induced by the first level, lower life cycling manifested itself in terms of a somewhat different cyclic response at the second, higher life level, CP loading. In the second level the material exhibited much higher cycle times, which, as the cycling went on, tended to approach the cycle times observed in the baseline CP behavior. The data in figure 3 show a trend that is reasonably represented by the linear damage rule. A prediction based on the damage curve approach is also shown, which, while providing a very conservative estimate for the results, does not adequately represent the observed behavior. The presence of creep damage in the second loading level appears to influence the cumulative damage behavior, implying that another damage mechanism is operative. Fractographic and metallographic analysis of the fractured specimens is currently underway to ascertain the nature of the damaging mechanisms operative in this type of cumulative fatigue loading.

The results of the two-level loading experiments involving CP followed by PP are shown in figure 4. In this series of tests the effect of the CP low life level cycling on the second, high life level PP cycling was to introduce a significant tensile mean stress as well as to produce a "harder", cyclic stress strain response than was observed in the baseline PP experiments at the same applied total strain range. This mean stress tended to relax somewhat as the second load level cycling progressed, but a significant mean stress was nevertheless maintained throughout the test. The life data shown in figure 4 were calculated assuming $R = -1$, and the results of these experiments indicate that the influence of the earlier CP cycling on the subsequent PP cycling is, at worst, virtually insignificant, and, at best, an enhancer of fatigue resistance at the second level. These results also indicate the possibility of another damage mechanism. Fractographic and metallographic analyses are in progress.

The results obtained thus far indicate that for this material in cumulative creep fatigue loading, the interaction between PP and CP loadings is not as deleterious as the interaction that occurs between PP and PP loading. This result suggests that another cumulative damage mechanism is operative when CP loading is followed by PP loading or vice versa. While this is not surprising (the SRP approach is predicated on the possibility of different damaging modes of straining), the direction of the influence in the cumulative case, is an unexpected experimental result. Future work will include characterization of the PP and PC and the PP and CC cumulative damage behaviors so that the development of a physically based model that describes the general cumulative damage behavior for this material under conditions of fatigue and creep-fatigue loading is achieved.

REFERENCES

1. Manson, S.S.; and Halford, G.R.: Practical Implementation of the Double Linear Damage Rule and Damage Curve Approach for Treating Cumulative Fatigue Damage, Int. J. Fract., vol. 17, 169-192, 1981.

2. Kalluri, S.: Generalization of the Strainrange Partitioning Method for Predicting High Temperature Low Cycle Fatigue Life at Different Exposure Times, Ph.D. Dissertation, Case Western Reserve University, Cleveland, Ohio, 1987.

3. Miner, M.A.: Cumulative Damage in Fatigue, J. Appl. Mech., vol. 67, A159-A164, 1945.

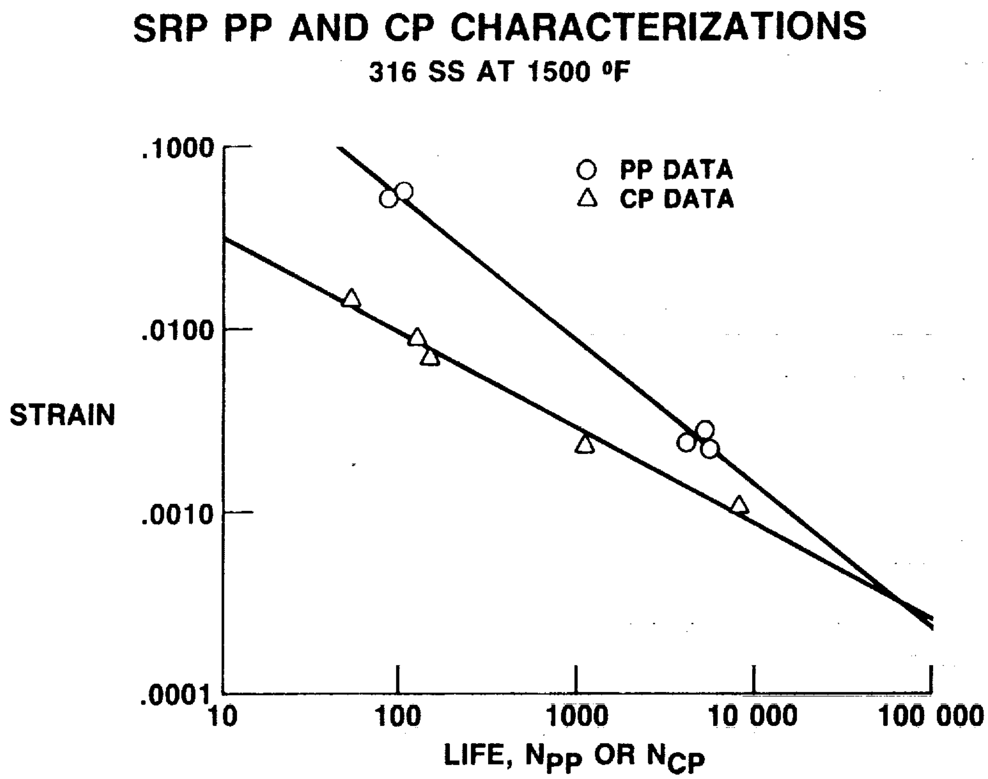

Figure 1

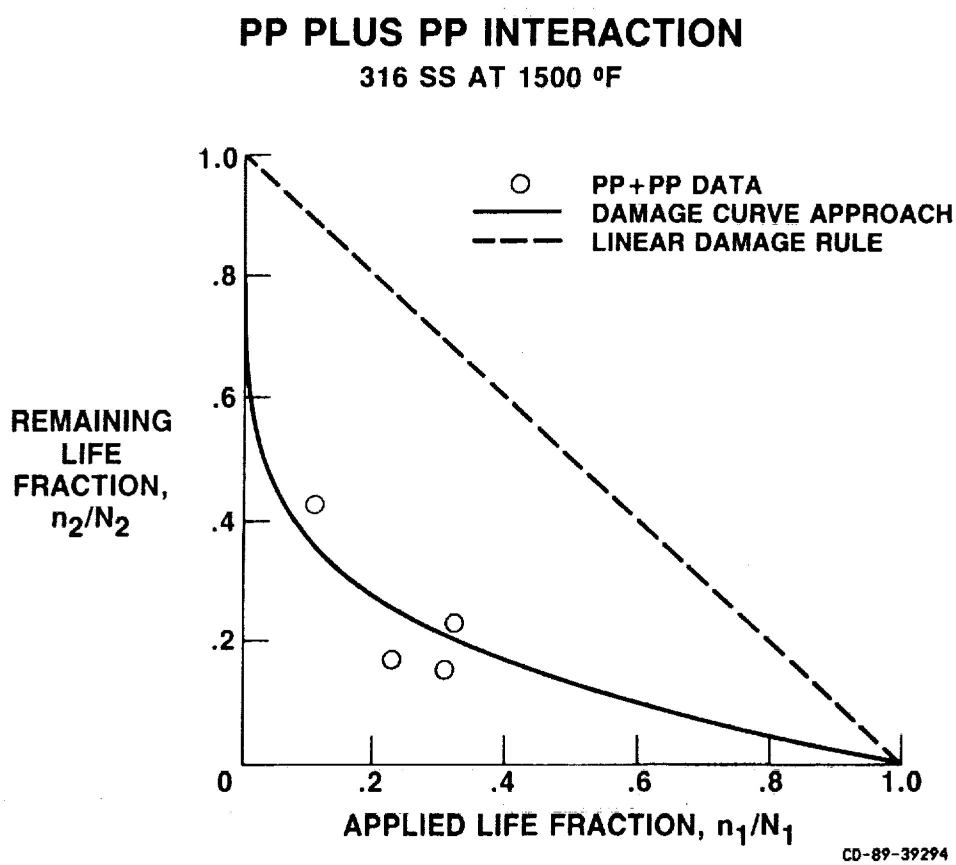

Figure 2

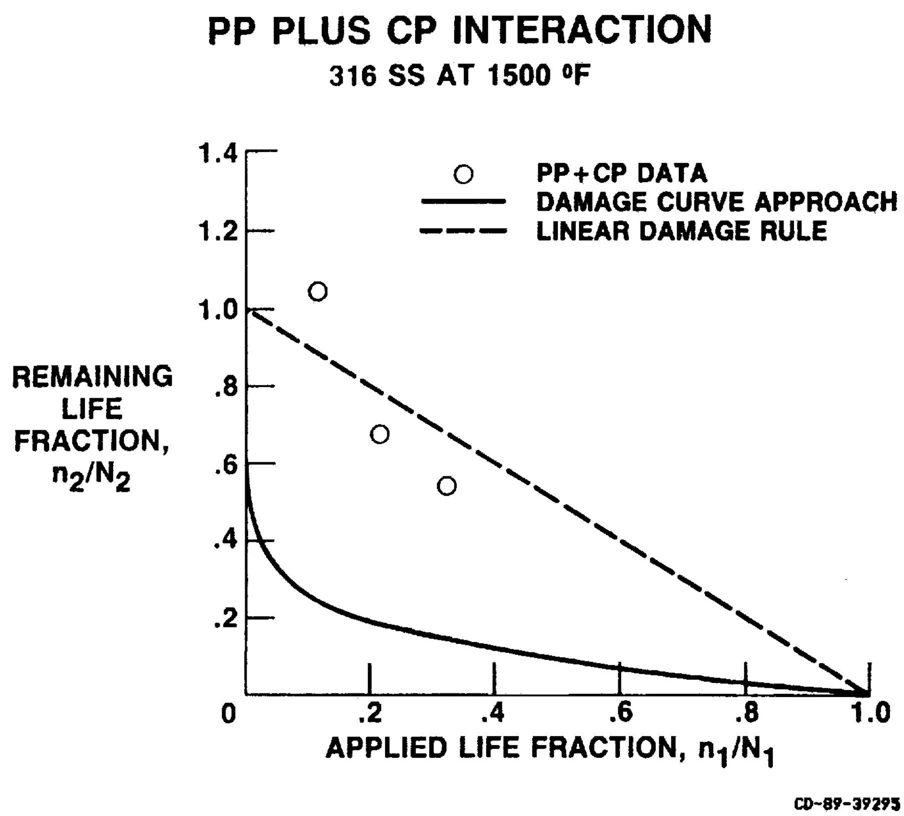

Figure 3

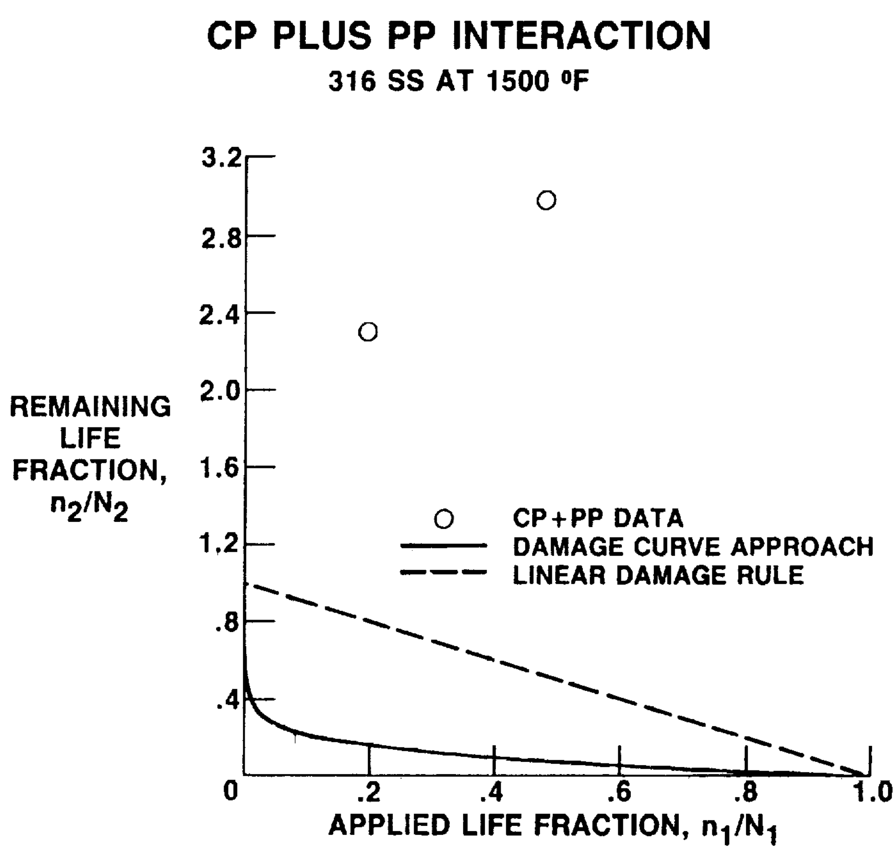

Figure 4